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TECHNICAL REPORT

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# RESEARCH ON ACOUSTICAL PROBLEMS OF THE MILITARY: A REVIEW AND FUTURE ASPECT

by

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October 1968

UNITED STATES ARMY
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U.S. ARMY MATERIEL COMMAND

Pioneering Research Laboratory

# ERRATA

Research on Acoustic Problems of the Military:
a Review and Future Aspect

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| READS | SHOULD READ |
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| **Cover**<br>Research on Acoustical Problems of the Military: a Review and Future Aspect | Research on Acoustic Problems of the Military: a Review and Future Aspect |
| **Page iv, appendix**<br>Conversion of pounds psi to Decibels | Conversion of Pounds per square inch to Decibels |
| **Page 6, at bottom**<br>2000 $H_Z$ | 2000 HZ |
| **Page 9, para. 1, 2nd sentence**<br>The APH-5 helmet (the standard combat vehicle crewman's helmet) both require improved attenuation characteristics at low frequencies. | The APH-5 (the standard aircrewman's helmet) and the CVC helmet (the standard combat vehicle crewman's helmet) both require improved attenuation characteristics at low frequencies. |
| **Page 9, para. 2, line 9**<br>Human Engineering Laboratories | U. S. Army Human Engineering Laboratories |

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## FOREWORD

The requirement for acoustic protection has been in evidence for many years to those involved with the treatment of acoustic trauma. Increased power of weapons and increased utilization of mechanized equipment has imposed even more stringent environmental stress on the individual soldier.

The acoustic environment is complex and the interaction of many forms of acoustic phenomena with the individual results in reduced individual capabilities through communications masking and temporary hearing loss as well as traumatic effects of weapons blast and high intensity noise.

Increasing hazards and traumatic effects, coupled with limited state-of-the-art advancement in the area of blast and acoustic attenuating materials and devices, emphasize the need for a continuing program of research and development in this vital area.

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## ABSTRACT

A review has been made of the literature in the area of acoustics, vibration, shock, and blast phenomena related to effects on the physiological system and attenuation effects of materials and devices.

In addition, information from sources other than the literature pertinent to an evaluation of the significance of acoustic hazards in the military environment, is also presented.

This review has demonstrated the severe acoustic hazards presented by the military environments and the inadequacy of presently available attenuating devices.

Damage-Risk and Standards Criteria are presented, and further studies are suggested to advance the state-of-the-art in acoustic hazards protection as well as to exploit the potentials of acoustic phenomena for the investigation of material properties.

# RESEARCH ON ACOUSTIC PROBLEMS OF THE MILITARY: A REVIEW AND FUTURE ASPECT

## Introduction

The environment in which the military man often finds himself has many hazards, not the least of which is the severe stress imposed on him by acoustic hazards, e.g., vibration, shock, and blast phenomena, all of which affect the physiology and the psychology of the soldier as well as the materiel supplied for his use or protection. It is the purpose of this report to assemble the essence of acoustic hazards, protective methods, and damage-risk criteria as a guide and heuristic device which will serve to inspire interdisciplinary efforts for the solution of acoustic problems.

To accomplish this purpose, a brief definition of "generalized acoustics" will first be provided, followed by a condensed review of past and current acoustic research and development problems. With this scientific background in mind, the reader can more readily see the urgent need for penetrating further into acoustical phenomena. The payoff for the military, considering the practical aspect, can be predicted to be (a) the reduction of acoustical hazards through modifications of the sources and (b) improvements in sound attenuating materials and devices designed to counter acoustic stress.

In addition, the advancement in the state-of-the-art of material properties and diagnostic techniques through generalized acoustic investigations will continue to benefit many disciplines in the life sciences as well as the physical sciences.

One area - one environment - which is of vital concern to all, especially the military, is that of generalized acoustics. Acoustics, in general, involves the mechanical transmission of energy through all media in the form of longitudinal wave propagation, and it embraces a broad scope of phenomena. Generalized acoustics will therefore be defined to include not only the phenomena associated with mechanical vibrations in the audible range of about 20 to 20,000 Hertz, but also those associated with longitudinal waves of frequencies from about $20X10^3$ Hertz (to about $10^{10}$ Hertz, practically) and above (termed ultrasonics) as well as longitudinal waves of frequencies below 20 Hertz (termed infrasonics). Within the context of the term there is contained not only the production, transmission and effects of sound as related to hearing, but also the effects of sound on all physical and physiological systems. Within the purview of the investigator also come vibrating systems which allow the generation and propagation of wave forms other than longitudinal (e.g., transverse flexural) and discontinuities in the acoustic field which result in shock waves. In gases, these latter may be accompanied by long durations of high pressure. These phenomena will be briefly discussed in the following sections in order to indicate the present position of acoustic knowledge and research.

Physical acoustics: Fundamental phenomena involved with the longitudinal vibrations in macroscopic bodies are well delineated in the literature (1) (2) (3) (61) and constitute a well substantiated, formal body of knowledge. Acoustic vibrations propagate as a series of condensations and rarefactions (i.e. a series of compressions and decompressions). Such vibrations may occur in any medium of any dimensions and, in general, obey physical laws which are analogous to those of optics. These vibrations may undergo reflection, refraction, dispersion, diffraction, interference, and radiation. This implies focusing, attenuation, resonance, and polarization phenomena so well known in optics. The form of a wave also influences its interaction. Therefore, the shape, rise time, and duration of transient impulses (e.g. shock and short bursts) as well as the frequency and configuration of recurrent wave phenomena determine not only the resonance and deformations of the interacting body but also the attenuation, diffraction, etc. of the incident wave itself.

Contemporary basic research is centered in the area of ultrasonics (3) (5) (42) (44), hypersonics (45), and nonlinear acoustics (3). Such problems as acoustic scattering from objects of a size comparable to the wave length of the interacting wave are of concern in the theoretical development of untrasonics. Ultrasonics research has been extensive in metallurgy, ranging from flaw investigations and phase transformation analysis to the effects of ultrasonic irradiation on metallurgical processes. Indeed, the whole of solid state physics has been transformed by ultrasonics through the definition of molecular processes, constituents, and configurations.

Probably the most investigated area in non-linear acoustics has been that of shock wave phenomena. Its effects on the production of rapid definitive thermodynamic changes in gases, liquids, and solids have made the shock wave a powerful parameter in the investigations of gaseous molecular phenomena as well as the mechanical properties of liquids and solids.

Physiological and Psychological Acoustics: (10) (11)

The responses of and effects on the physiological system resulting from acoustic energy have been the subject of intense investigation over the past century. The definition of the conduction process (25) (26) from the ear drum through the ossicles, through the cochlear fluid to the hair cells in the basilar membrane, and the definition of its various responses, have enriched our understanding of the auditory mechanism. But this knowledge has also raised new questions concerning the differences in susceptibility to damage of various portions of the auditory mechanism, and, despite many theories, there is still no completely acceptable theory of the hearing process.

Studies utilizing mechanical models (21) (23) (24) have shed much light on the mechanical interactions within the ear. Further research in this area may provide information relating mechanical and neural responses as well as advancing the knowledge of mechanical responses of the auditory system under diverse environmental conditions.

The utilization of ultrasonics in therapeutics (42) as well as in diagnostics (42) have also opened new vistas and have provided new and powerful artifacts for the field of medicine. The employment of ultrasonics in the areas of biology fall into three general categories. (a) Low intensity ultrasonics absorption measurements in proteins have clarified their contribution to absorption in tissues. Such measurements are being extended to other molecular species. (b) In an intermediate intensity range ultrasonics has been utilized in therapy and soft tissue structure visualization. (c) High intensity ultrasonic energy has been utilized to effect permanent changes deep within tissue without adversely affecting intervening structures. Under specific conditions of irradiation, such irreversible results have been observed without thermal or cavitation effects.

The region of infrasonics (22) has recently become significant since the development of rocket motors and it is anticipated that more stringent requirements for protection will soon become evident.

Efforts in the field of psychoacoustics (27) (29) (30) (31) (32) have bordered on many areas of physics and physiology and have supplied considerable information, not only concerning the sensation of sound and its relation to human perception and behavior, but also its permanent and temporary effects on the physiological system. Although considerable effort has been expended, the problem of estimating the subjective responses of individuals exposed to various sounds and noises by means of physical measurements on sound waves in air, still has no satisfactory solution.

Applied Acoustics and Related Phenomena:

Elastic vibrations (2) (3) of material bodies in various phases have been extensively investigated, and mechanical engineering journals as well as physical science journals are replete with such studies. Elastic waves may propagate as either purely longitudinal (when particles vibrate in the direction of propagation), purely transverse (when particles vibrate in a direction normal to the direction of propagation), or flexural, extensional, and torsional (which are combinations of longitudinal and transverse motions).

Applications in the region of macroscopic elastic vibrations mainly involve engineering, but many other disciplines benefit. Such applications relate to dynamic structural design, auditorium acoustics, shock and vibration isolation, underwater sound signaling (sonar), structural strength in vibratory or impact environments, acoustic attenuating devices, and structural strength in a cavitation environment in liquids. Again as in other branches of acoustics, the sound field in engineering applications is an investigative technique and tool as well as a hazard which must be protected against. It may stimulate the production of, as well as be produced by, other elastic vibrations.

As a tool, elastic vibrations have been utilized to drill, cut and carve hard materials, relieve welding stresses, and to control friction. Elastic vibrations are also used as an aid in separating metal work from dies without lubrication.

Acoustic instrumentation has progressed to a high level of sophistication in the past fifty years. There is a variety of sound level meters available which are compact and yet are sensitive, accurate, and versatile in measuring sound levels over significant bands of frequencies. In addition, such instruments have been modified to measure certain impact and vibration levels. The frequency spectra of complex wave forms can be analyzed by accurate and reliable wave analyzers. An impressive array of transducers are currently in use for acoustic as well as other elastic vibration measurements. Such transducers involve many ingenious innovations in physical principles. A wide range of vibrations and displacements can be measured utilizing various resistance wire and semiconductor strain gages. These gages may be assembled in various forms to measure acceleration, force, and many other variables pertinent to elastic vibrations. Piezoelectric, capacitance, and inductance transducers of many varieties complement, and in many cases supplant, resistance transducers. Advances in electronics have also made possible a proliferation of easily controllable sound sources from pure tones to a wide range of harmonic content waveforms.

## ACOUSTIC PROBLEMS OF THE MILITARY AND EFFORTS TO SOLVE THEM

Acoustic Hazards: The military environment abounds with a diversity of acoustic hazards from a wide variety of sources. The sources (4) (10) (11) of generalized acoustic vibrations may be characterized by their emission for the purpose of investigating their effects on a given receiver. Conditions of the source such as position, environment, and direction affect the magnitude of the noise. In addition, the quality and magnitude are also affected by combination with other noises.

Modifications of vibrations in the source itself is, of course, the province of the source developers (e.g., tank and gun developers) although liaison should and does, in many instances, exist between source developers and designers of individual protective devices.

Figure 1 (6) (16) (18) (28) (33) (43) illustrates typical acoustic hazards of the Military with pertinent damage-risk criteria. The indicated bone conduction threshold represents the limit of attenuation obtainable by perfectly occluding the ear passage.

The noise levels in tanks (e.g., T196E1 self-propelled howitzer) and those imposed on maintenance crews in the vicinity of jet engines are above the damage-risk criterion, but research and development on improved attenuation in helmets offer encouragement that sufficient protection will soon be available in this area.

It is interesting to note that the noise from rifles exceeds the tentative damage-risk criterion for impulsive noise and these weapons are normally operated without benefit of ear protection.

The impulsive noise level in the crew areas of the 107mm mortar and 105mm howitzer are far above the damage-risk criterion for impulsive noise and although the howitzer is operated with crew members wearing ear plugs, the attenuation given by the ear plug (Figure 2) is not sufficient to reduce the noise level below the tentative damage-risk criterion.

The pressure which would result from more powerful weapons approaches or is within the range in which organic injury to the lungs as well as the ear could be expected if proper protection is not afforded (9) (40).

Physiological Effects and Masking: The human receiver on which the acoustic energy impinges is not only affected by such waves of energy, but also modifies them. The receiver may be so altered that subsequent acoustic effects are either diminished or even enhanced. Muscles may contract during or after interaction with acoustic waves and the resulting change in tissue compliance alters its response to vibrations. In addition, tissues may degenerate after repeated exposures resulting in altered system response which, in turn, could

result in attenuation or enhancement. Enhancement could also occur when certain tissues or cavities are excited to resonance. Such responses vary from one individual to another. The human ear is, however, not only variable in susceptibility from one individual to another but also in time for a single individual. Trauma may result, in addition to such effects, taking the form of degenerated hair cells in the basilar membrane (which results in loss of hearing) or ruptured ear drums (which in some instances has served to protect the hair cells of the basilar membrane from damage). Other portions of the human anatomy also respond adversely to high intensity sound and blast (9) (40). Evidence indicates a relation of such damage to body cavities.

Figure 3 (17) represents a method of assessing the masking effect of noise on communications. The curves indicate the voice sound level necessary to achieve effective communication in the given noise level environment. It will be noted that, at the higher noise levels, the voice level for effective communication may exceed the damage-risk criterion.

A more recent study (46) suggests that at 0.5/1/2 SIL's*(speech interference level) above 100 db., complete noiseproofing is necessary.

Figure 4 (6) illustrates another method of assessing the masking effect of noise on communications based on the percentage of words clearly understood in a given noise environment. It will be noted that, at the higher noise levels (above 85 db), the percent word articulation is increased when ear plugs are worn, over that when they are not worn. It has been suggested (64) (65) that speech intelligibility research should be pursued until 100% speech intelligibility is achieved. The reasoning behind this statement is that an error in even one word could result in unalterable consequences, as has been demonstrated in several aircraft accidents.

Figure 5 (43) illustrates temporary hearing loss resulting from exposure to impulsive noise with the sound pressure level for the 105 mm howitzer indicated. Such temporary hearing loss, as well as contributing to the susceptibility to permanent hearing loss, also impairs communication as indicated in Figure 6 (33). Even lower levels of impulsive noise, as indicated in Figure 7 (43) result in impaired communication and susceptibility to permanent ear damage.

Figure 8 (7) indicates permanent hearing loss resulting from noise and gunfire. It will be noted that as much as 40% of the ears with greater than 20 db hearing losses were in the speech-hearing range of 300 to 4800 cps.

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*SIL's are based on arithmetic averages of noise levels in octave bands. 0.5/1/2 indicates the SIL for octave bands centered at 500, 1000, and 2000 $H_z$.

Acoustic Attenuation: The attenuation of acoustic energy could be accomplished by merely supplying sufficient weight of attenuator and distance from the source. In general, there are limitations on both size and weight of attenuators.

1. Materials:

Sound attenuating materials absorb sound energy by transforming it into heat energy, either directly or by first transforming it into another form of elastic vibration. Materials which perform this task are relatively few and are generally inefficient at high intensities. The problem of energy conversion is made more difficult by the requirement that the material not fracture or undergo plastic deformation in the process of energy absorption.

2. Systems (6) (7) (8) (12):

a. Ear protectors: (19) Ear protectors may be divided into two categories; ear inserts and ear muffs. Each category involves several different forms and in certain instances both inserts and muffs are utilized together, giving not the combined attenuation but only somewhat better than either one. The limit of attenuation given by such structures is that established by the threshold for bone conduction which varies from about 40 db to 50 db* above the air conduction threshold. It is interesting to note that occluding the ear passage by pressing the tragus against the ear canal opening has resulted in from 40 db to 50 db attenuation, although a recent study (47) has indicated an attenuation of only 30 db to 40 db.

b. Helmets: (35) Helmets, mainly used for crash protection, must also provide communication and noise attenuation systems. There have been, however, no helmets utilized mainly for the purpose of sound attenuation outside the laboratory. If sound properties of the helmet are not taken into consideration, amplification of sound could result.

c. Suits: The utilization of complete suits as protection against intense acoustic radiation has been the subject of speculation for many years. Such suits have not been considered practical because of the large mass of material necessary to absorb the sonic energy from a continuous high intensity sound field. However, recent studies indicate the possibility of protection against transient acoustic energy (e.g., blast waves and short sonic bursts). Such studies have also indicated the possibility of optimizing protection against transient acoustics without the necessity of complete body coverage.

Attenuating Devices:

1. Ear plugs: (36) (37) (38) (39) (43) Many forms of ear plugs have been used and are available for acoustic protection. These range from simple wax impregnated cotton to formed rubber inserts with valves. Proper closure of the ear canal by the plug is most important in determining the effectiveness of the plug. The standard Army ear plug (V-51R Mine Safety Appliance Company) gives

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*All decibel ratings in this report are referred to .0002 dyne/$cm^2$

an attenuation of approximately 25 db at low frequencies (125-1,000 cps) and approximately 35 db at high frequencies (1,000-8,000 cps) provided that they are properly fitted, inserted, and used by healthy men. However, ear plugs have several major deficiencies; (a) they must be properly fitted and inserted to be effective, (b) they may work loose through jaw movement, (c) they are uncomfortable and cannot be worn by everyone.

2. Ear Muffs: (36) (38) (39) (41)

Ear muffs, too, are of many varieties. Essentially, they consist of a hard outer shell with a light elastic sponge material on the inside and a soft, pliable outer rim on the hard shell. The muffs are held against the head by a spring headband with varying degrees of comfort. The seal around the rim of the shell is important in insuring the designed sound attenuation. The standard Army earmuff (MSA Noisfoe Mark II) provides 8 to 10 db of sound attenuation at low frequencies (125-500 cps), an average of 25 db between 500 to 2,000 cps, and a maximum of 55 db at 4,000 cps. Two other earmuffs have been recommended for adoption as Standard A type for use by the Army, the David Clark Model 372-8A (Air Force Standard) and the Wilson 258 Protector*.

3. Helmets: (13) (14) (18) (34)

Although aircrewmen's helmets have been utilized primarily for crash protection, it has been found necessary due to increased noise, to provide them with acoustic attenuation. It is, in general, not the helmet itself which improvements in sound attenuation are mainly aimed at, but the ear muff attenuator within it. Such attenuation had eariler been recognized as essential to tank crewmen, although much improvement is needed. The CVC helmet has, however, been essentially useless as an attenuator at low frequencies. The standard Army aircrewman's helmet (APH-5) has an attenuation of approximately 30 db at high frequencies even though there is little or no attenuation below 500 cps. Two contracted studies are now in progress for the improvement of low frequency (below 500 cps) attenuation of the aircrewman's helmet. One such study now being conducted by Bolt, Beranek, and Newman Co. has evolved three attenuator concepts; a miniature exponential horn (which has proven impractical for incorporation in a helmet) and a differential dual shell muff (which has shown little improvement over the standard ear muffs due to the critical nature of the variables in a practical design). The third concept (66) utilizing a friction-spring cup cushion is anticipated to successfully attenuate 15 db or more at low frequencies. Another study being conducted by Columbia Broadcasting System Research Laboratory has also evolved two attenuator concepts; a small chamber (Helmholtz resonator) added to an ear muff has been evaluated and shown to provide approximately 20 db attenuation at low frequencies (below 500 cps). However, the feasibility of incorporating such a device in the helmet is still uncertain. One other device has undergone preliminary study and shows promise of being incorporated in the standard helmet. This device also has shown an attenuation of approximately 20 db at low frequencies (34).

*Recently made an Army Standard

Figure 2 (6) (34) (35) (43) (48) (49) (50) (67) represents the attenuation characteristics of some commonly utilized devices. The APH-5 helmet (the standard combat vehicle crewman's helmet) both require improved attenuation characteristics at low frequencies. Research and development programs, mentioned earlier, are underway to provide such additional attenuation. It must be noted, however, that both the Navy's BPH-2 and SPH-3 have attenuation characteristics which are superior to the APH-5 and they have consequently been recommended for adoption by the Army. It is observed that the greatest attenuation is obtained by utilizing both ear plugs and muffs. However, this is impractical in most situations.

Blast Effects: A review of past and current problems in blast effects on personnel discloses several areas that appear to be of growing significance (28). These areas involve the following problems: (a) Whole body discomfort has been experienced by artillery crewmen as a result of blasts of present guns. This effect has been demonstrated at pressures on the order of 7 psi. (b) Ear drum rupture has resulted from impulses on the order of 6 psi (depending on duration and individual physiological variation). Present artillery will produce pressures in the crew area of this magnitude and the use of ear plugs is mandatory. Human Engineering Laboratories has recommended, however, that personnel not be exposed to impulses greater than 7 psi even when using ear plugs. (c) Considerable temporary hearing loss (up to 75 db at 2,000 cps) has been observed to occur after 100 rounds of M14 rifle fire during a 15 minute period. The peak sound level was 160 db (.3 psi). HEL considers that a problem exists for an impulse of 160 db for 250 microseconds. (d) An impulse on the order of 15 psi may begin to produce internal tissue injury, again depending on duration. (e) An impulse pressure on the order of 30 psi, however, approaches the threshold of lethality and may even involve translational forces on the individual.

It was recommended at a meeting held at HEL that studies be initiated for the protection of guncrewmen from blast effects of proposed high energy artillery involving (a) the development of a man simulator, (b) the study of shock propagation around a typical gun, and (c) the study of materials and geometries for deflecting and attenuating gun blasts.

The Army Concept Team in Vietnam: A request was made directly to the Army Concept Team in Vietnam (the organization in that area responsible for in-field evaluations ) to obtain the following general information: (a) A subjective evaluation of the effects of noise, vibration and blast on the soldier resulting from operation of machine guns, mortars, artillery, tanks, and helicopters. This evaluation should relate to known discomfort, communication problems, and job efficiency. (b) Limitations of currently available noise protective devices in the combat environment. (c) Organic injuries and efficiency impairment resulting from blast, noise, or vibration.

Response from the Army Concept Team in Vietnam indicated the following:

It was felt that the results of exposure to the specifically mentioned acoustic hazards were already in the literature and that it was unlikely that the specific environment or tactical situation in Vietnam would result in significant differences. The writer has surveyed the literature extensively

and has found much investigation of acoustic hazards resulting from many specific weapons and equipment used in the military (but there were no comprehensive studies on all available weapons and equipment). The normal military environment, in general, involves many types of acoustic hazards either simultaneously or within short periods of time. Such a general environment has not been studied (although a recent study of two combined noise types has been made (60)) and extrapolations from specific hazard environments to mixtures of various acoustic hazards is not necessarily valid. In addition, differences in acoustic effects resulting from natural environmental conditions (20) (52) (53) have been noted in the literature.

The Army Concept Team in Vietnam further studied information which they received from the divisions and aviation groups, that indicated no significant problem of acoustic injury. They reviewed clinical records and considered that these did not reveal a significant number of organic problems resulting from exposure to acoustic energy sources. There is, however, considerable disagreement as to what constitutes a significant problem or significant requirement. The Army Concept Team also concluded that currently available noise protective devices are subjectively sufficient. They expressed the opinion that a subjective evaluation does not reveal many significant effects and that an extensive objective study of the entire problem area, utilizing the resources of the Office of the Surgeon General, is warranted.

Hearing Loss Statistics: Recent data* from Army installations indicate that 50% of range personnel have incurred drastic hearing losses and must be relieved of their normal duties. A recent report (51) states: "Records of the Veterans Administration show that well in excess of 50,000 veterans list loss of hearing as a primary disability. The annual cost to the VA for compensation, hearing aids, batteries, and repairs is over 36 million dollars, and the cost is increasing at the rate of $3.5 million per year. According to statistics compiled by the Walter Reed Army Medical Center, 47.5% of all cases of disability caused by loss of hearing are directly attributable to the noise of gunfire. The incidence of hearing loss is increasing, probably because of the higher noise level produced by modern weapons."

In addition to the hazardous effects of impulsive noise, it has been determined that the noise levels in tanks are also excessive and hazardous.

Additional insight into the acoustic hazards may be gleaned from the recent review of F. G. Hirsch (54) of the Lovelace Foundation. This review, concerned with traumatic effects of blast overpressures on the ear, indicates the lack of quantitative data relating such overpressures to ear injury.

A brief review by A. E. Hirsch (55) of David Taylor Model Basin, also reveals the need for further information relating injury to blast parameters. It is also suggested that presently accepted damage-risk criteria are too high.

*Information obtained by Army Medical Research Laboratory, Fort Knox.

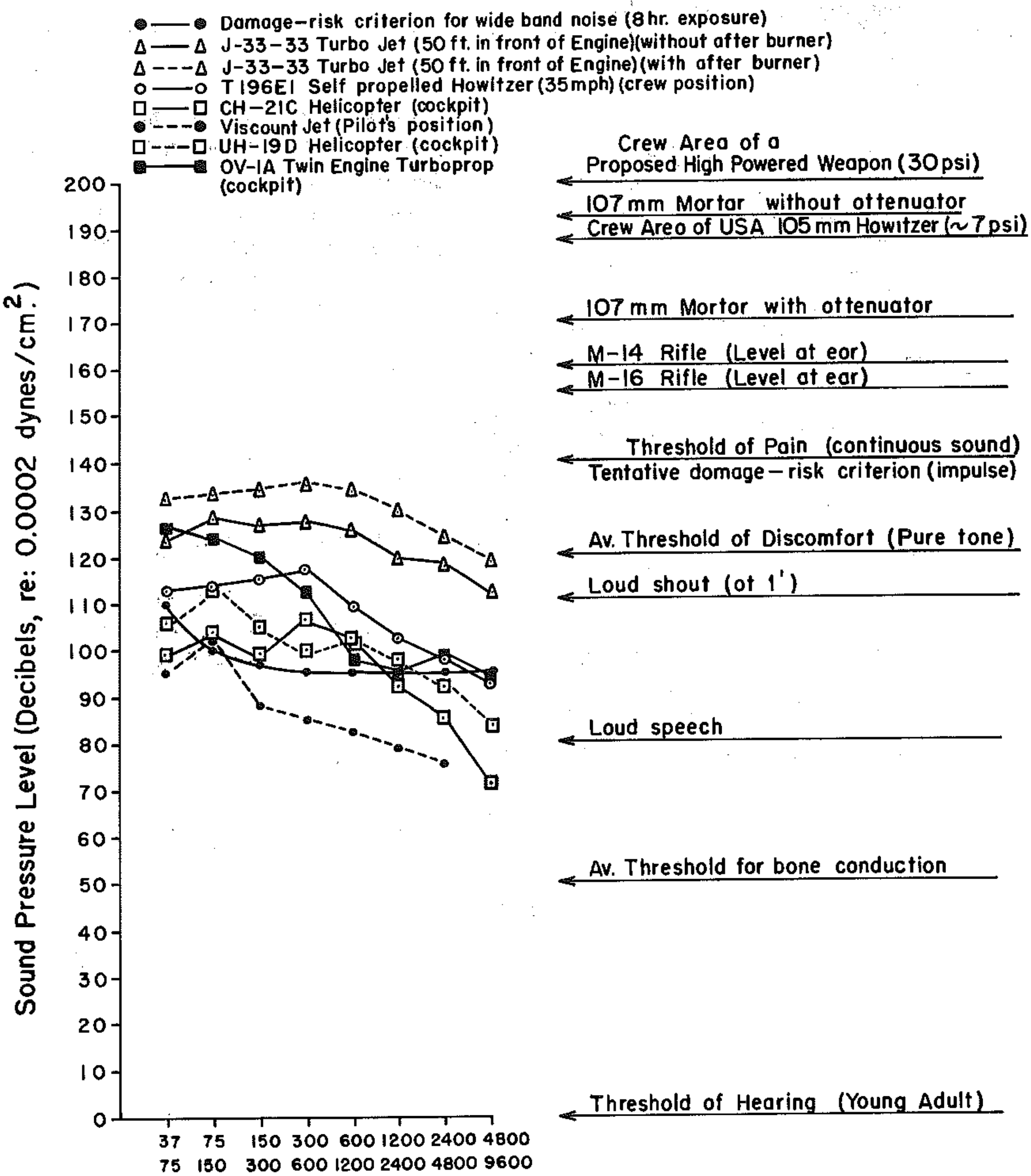


Fig. 1 Acoustic Hazards

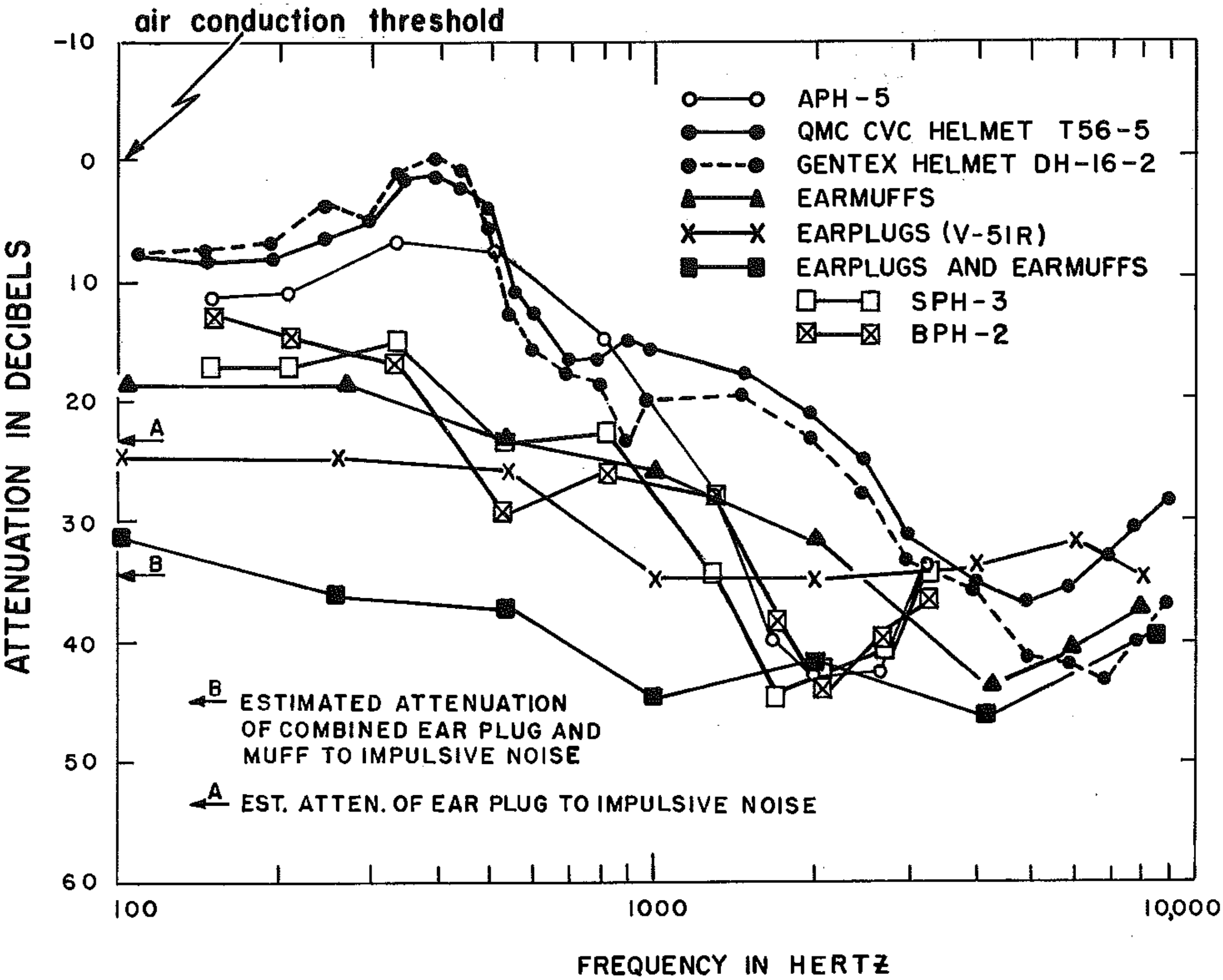


Fig. 2 Sound attenuation characteristics of sound attenuating devices and helmets

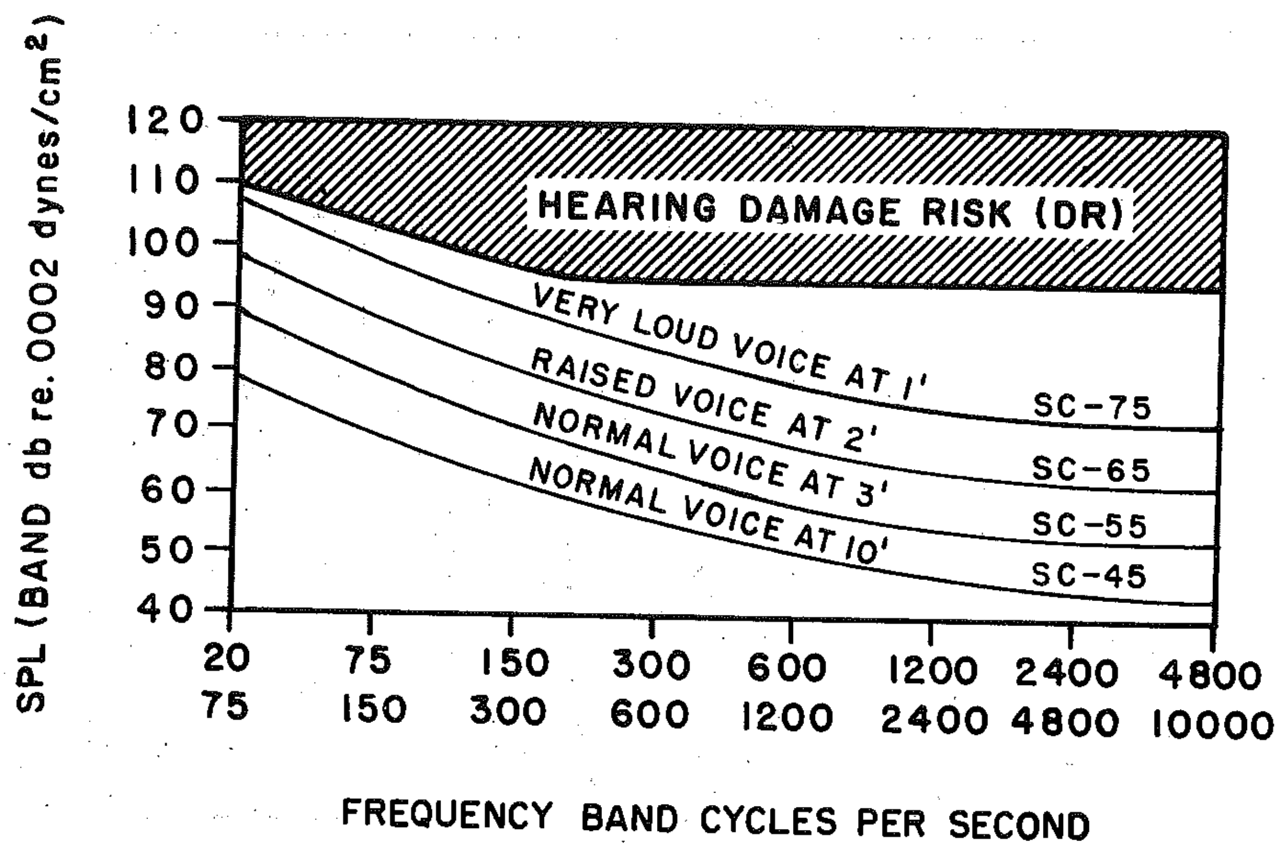


Fig. 3 Hearing Damage-Risk and Speech-Communication (SC) Criteria

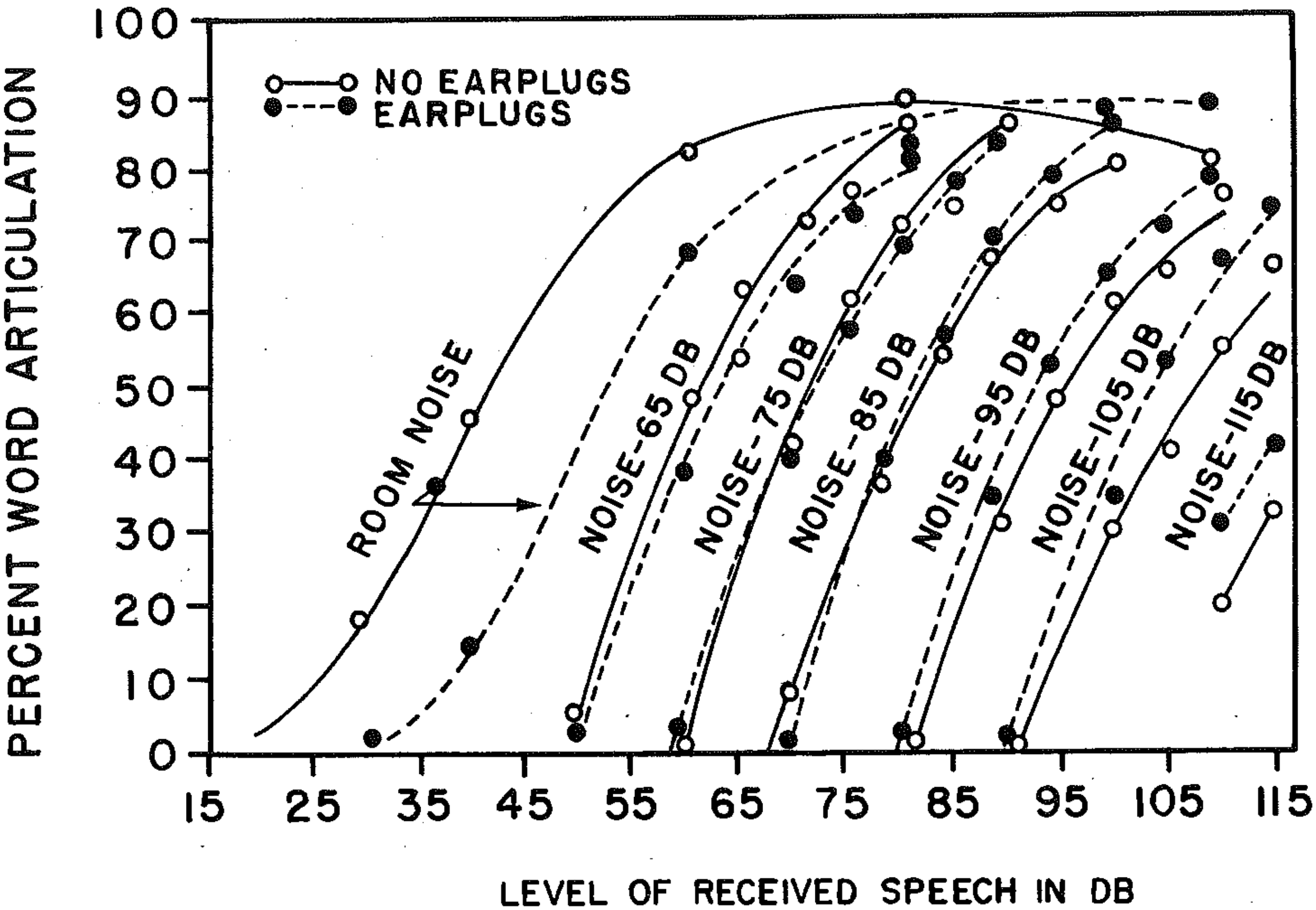


Fig. 4 Word articulation with and without earplugs in a noise environment

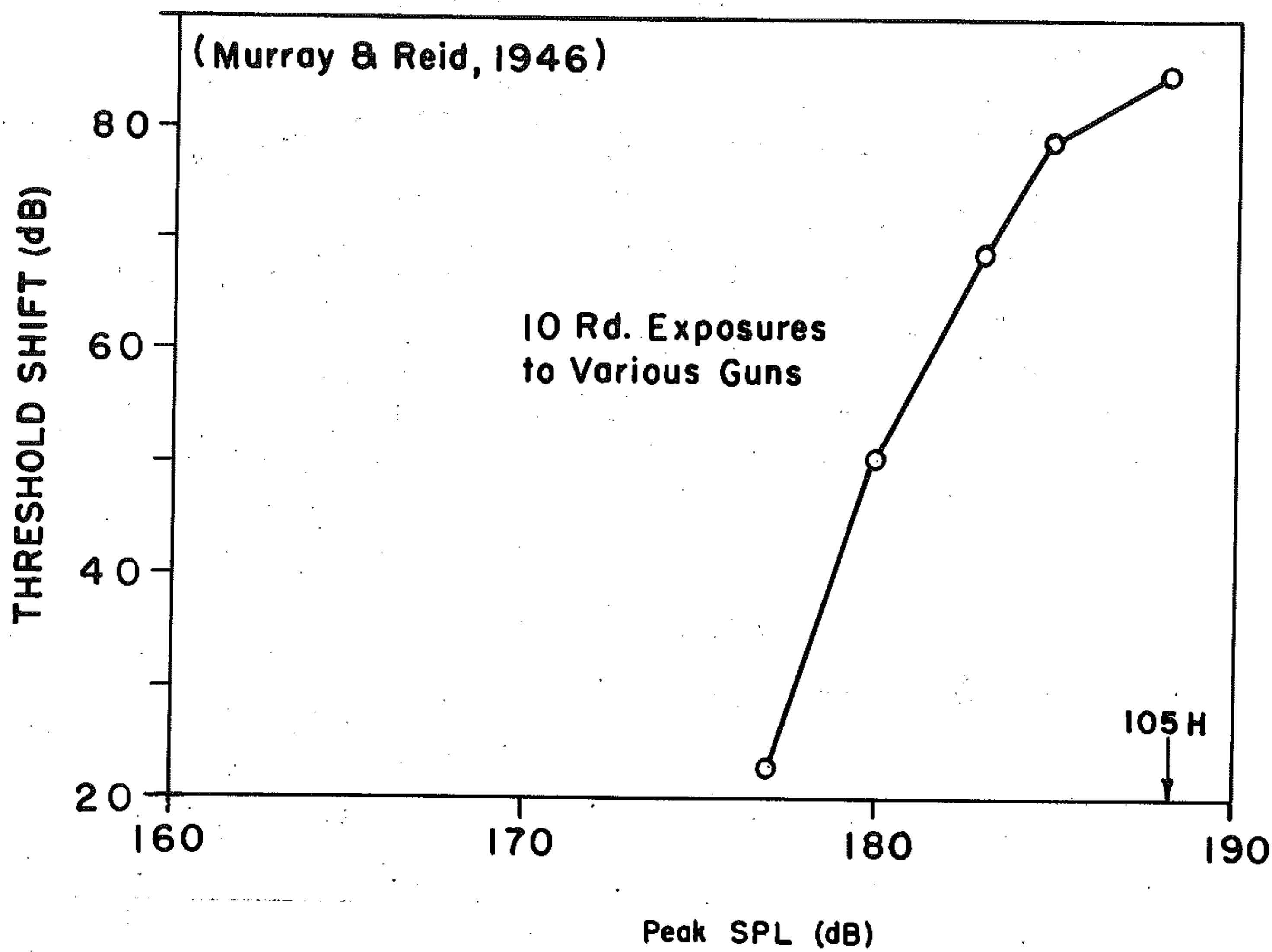


Fig. 5 Temporary threshold shift for impulsive sound (high level)

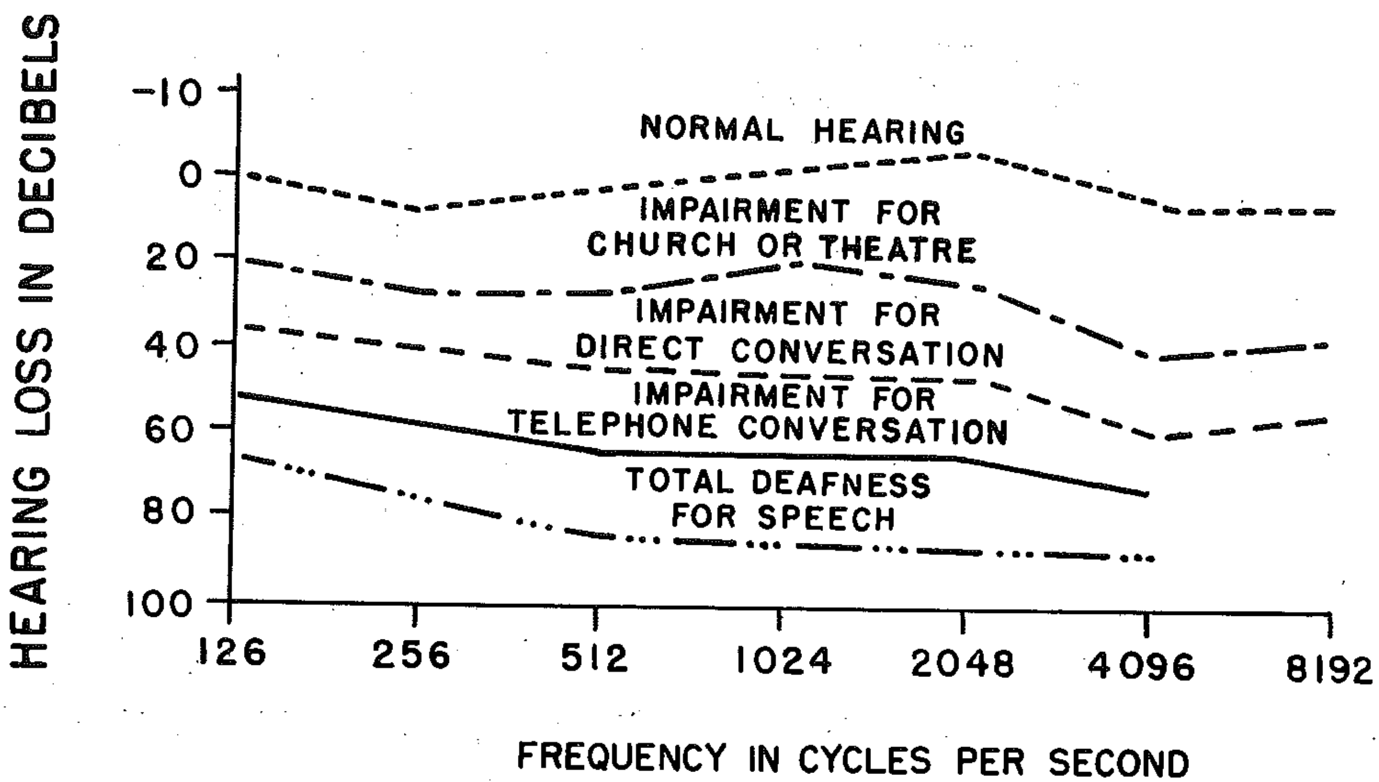


Fig. 6 Effect on voice communication of various degrees of hearing loss

(After Woodson, 1954)

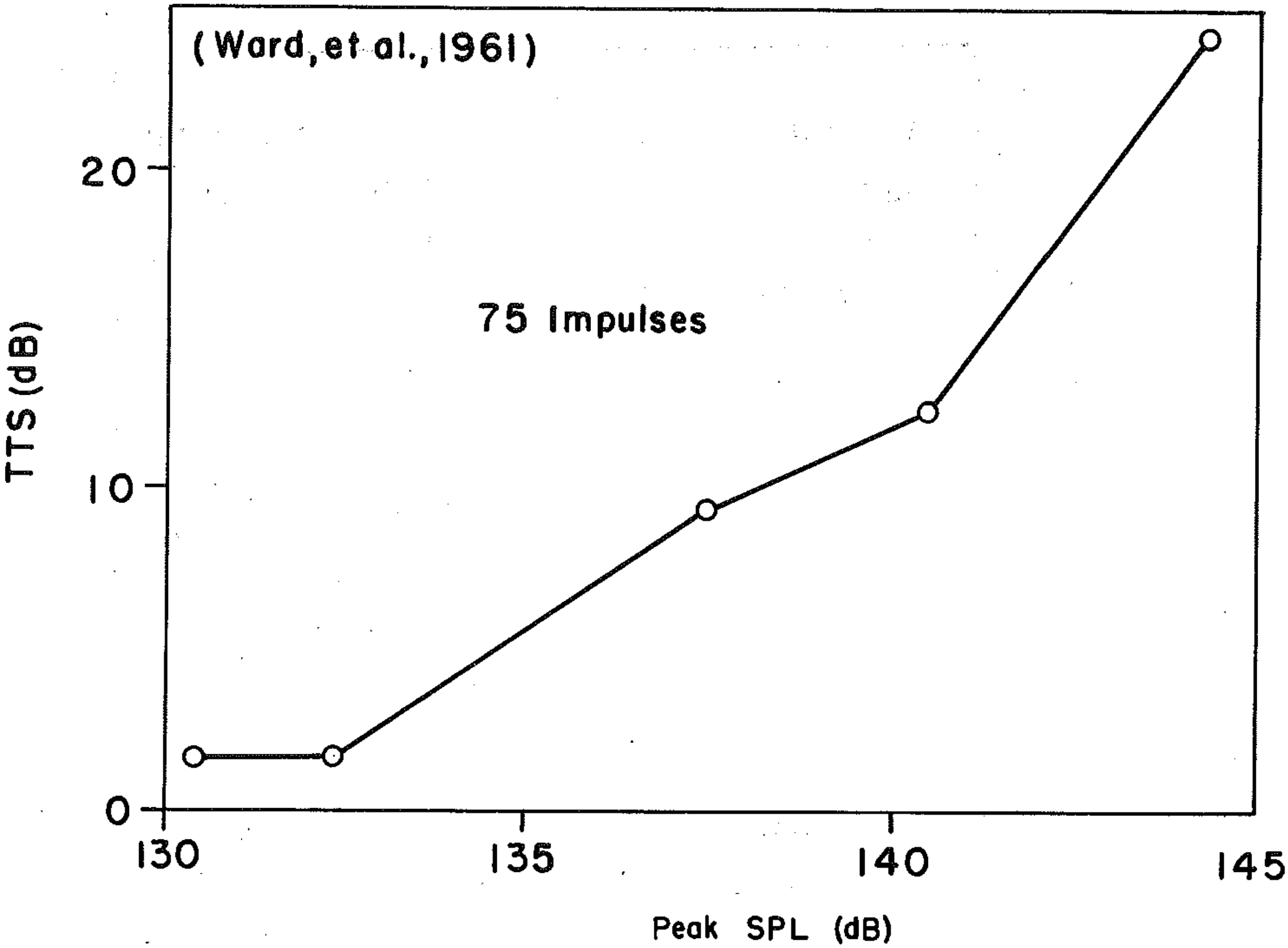


Fig. 7 Temporary threshold shift for impulsive sound (lower level)

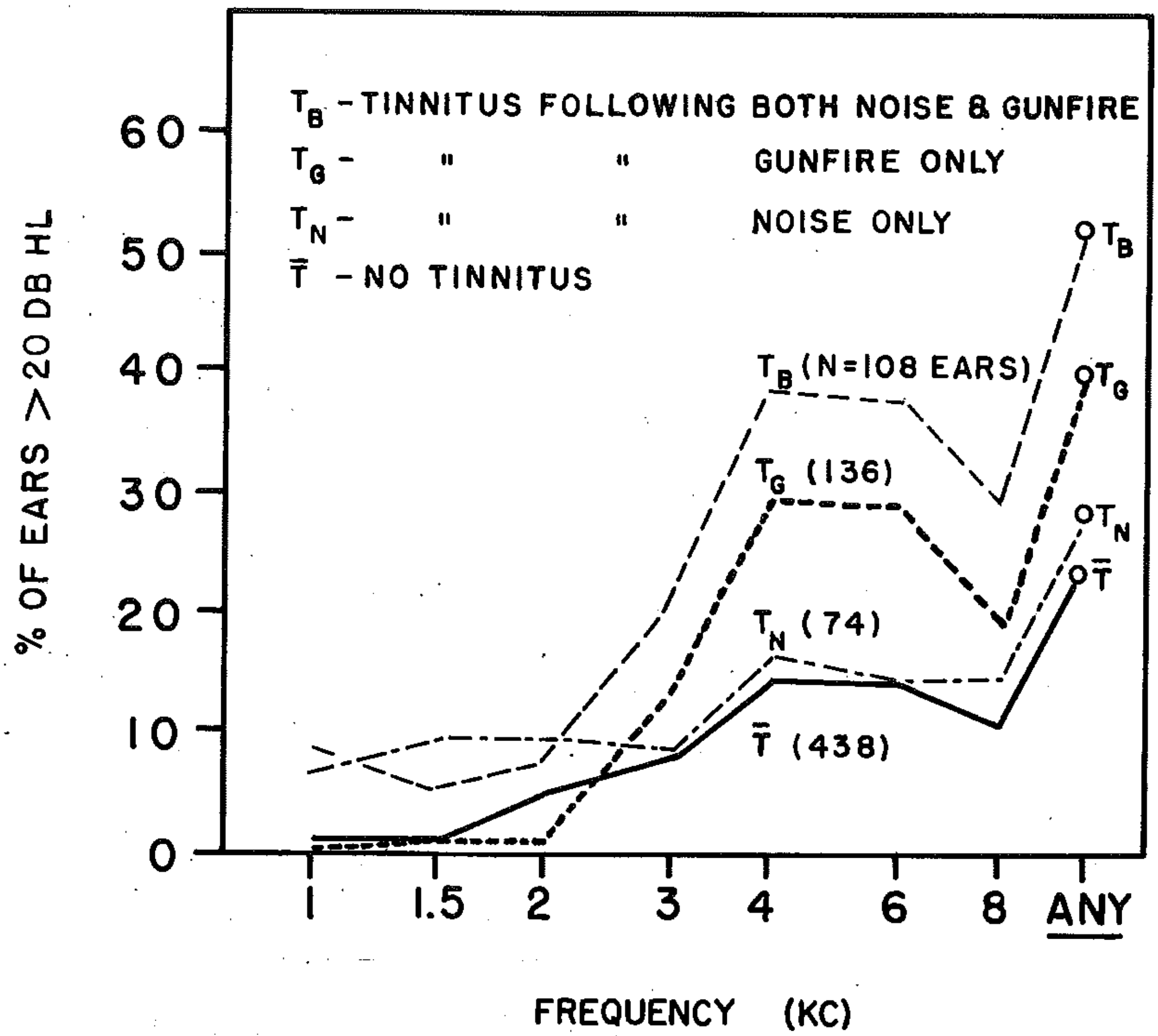


Fig. 8 Percentage of ears with 20 db HL or more as a function of frequency. The parameter is type of tinnitus reported. Noise-exposed personnel only.

Criteria for Protection: The requirement for protection against acoustic hazards implies a need for adequate criteria on which to base the necessity for and effectiveness of such protection.

Many criteria have been developed for a variety of conditions and are based on temporary and permanent hearing threshold shifts from a diversity of sources. These criteria, however, indicate risk for a certain segment of the exposed population under special conditions and should not be generalized.

Figure 9 is a comparison of some major damage-risk and standards criteria for continuous wide band noise. The NAS-NRC criterion (12) is given for an 8 hour exposure per day, as is the Benox report criterion. The MIL-A8806A specification (56) is the maximum acceptable noise for aircraft interiors which are occupied by crewmen at normal cruise power (this contour is raised at the low frequency end when protective helmets are worn or for higher power short duration conditions). The HEL standard (57) is the maximum steady state noise level for Army Materiel Command equipment. Although the HEL standard and MIL-A8806A specification are not meant to be used as damage-risk criteria, their comparison with accepted damage-risk criteria is instructive. Care should be exercised in such a comparison to insure that protection to the same levels of population are being considered. It is interesting to note that there is a spread of at least 10 dB between some contours, and that such a displacement above the Benox report criteria was considered (in the report) to result in significant increases in hearing loss whereas 10 dB lower would involve negligible risk.

A recent publication (58), relative to diesel-engine room noise, indicates that a damage-risk criterion of 100 dB at any relative octave would protect more than 85% of the population considered.

In general, the criteria are not considered as sharp demarcation lines, but rather as contours which define areas for which there is greater and lesser risk of a certain degree of permanent hearing loss.

Figure 10 gives the maximum acceptable impulse noise parameters for Army Materiel Command small arms (57). Positive pressure duration is defined as the time required for the pressure wave to rise to its first positive peak and return momentarily to ambient. Positive pressure envelope duration is defined as the time required for the pressure wave to rise to its highest positive peak and to decrease to and remain 20 dB below this highest peak.

Figure 11 (59) indicates a damage-risk criterion for impulsive noise. The A-duration and B-duration are defined in a similar manner to the positive pressure duration and positive pressure envelope duration respectively in Fig. 10. This criterion indicates the peak pressure level and duration limits for impulses having near-instantaneous rise times that will not produce an excessive risk of hearing loss to a majority of those exposed. The criterion is based upon repetition rates of 6-30 impulses per minute for a total of 100 impulses per exposure.

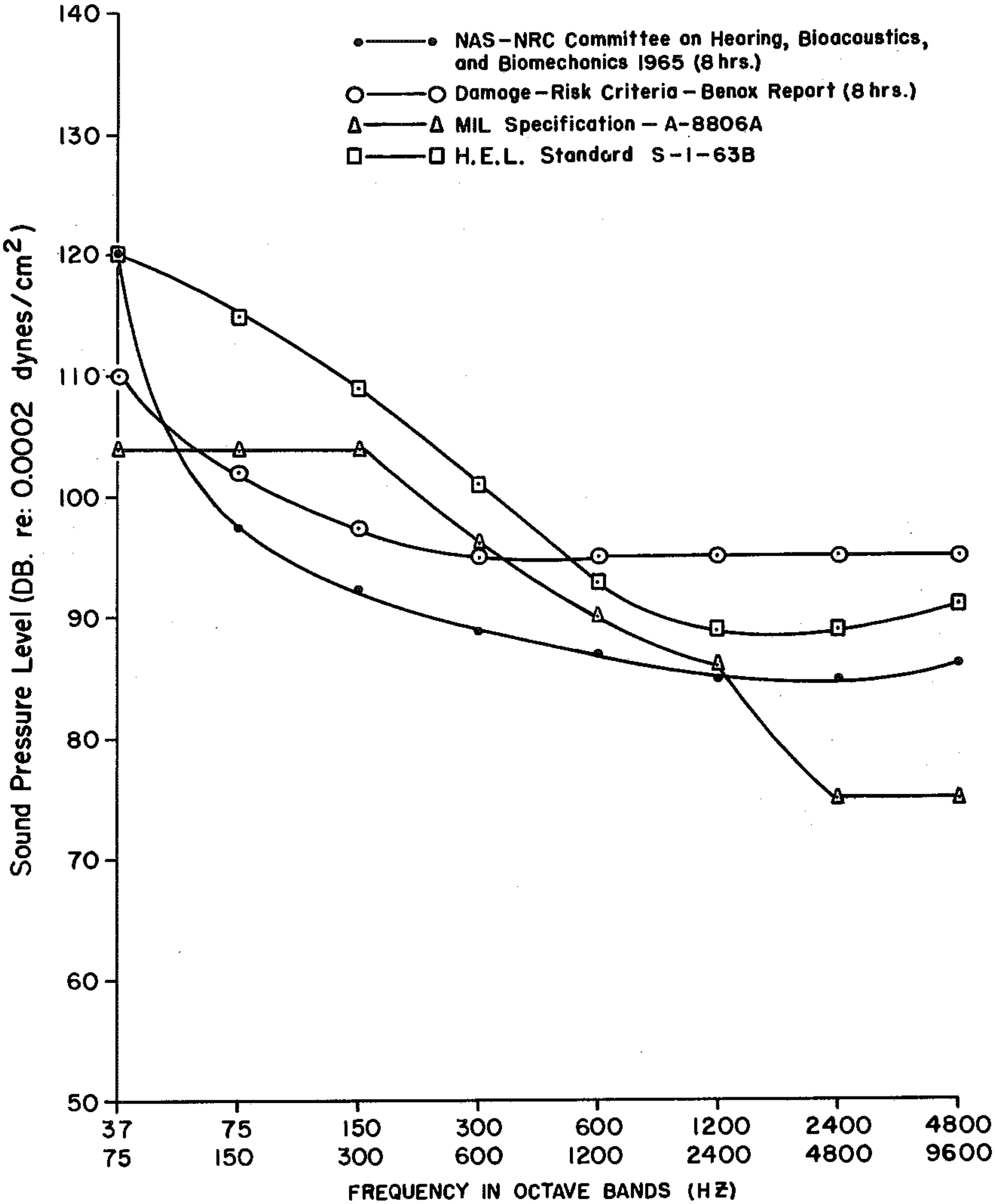


Fig. 9 Major Damage-Risk and Standards Criteria for Continous Wide Band Noise

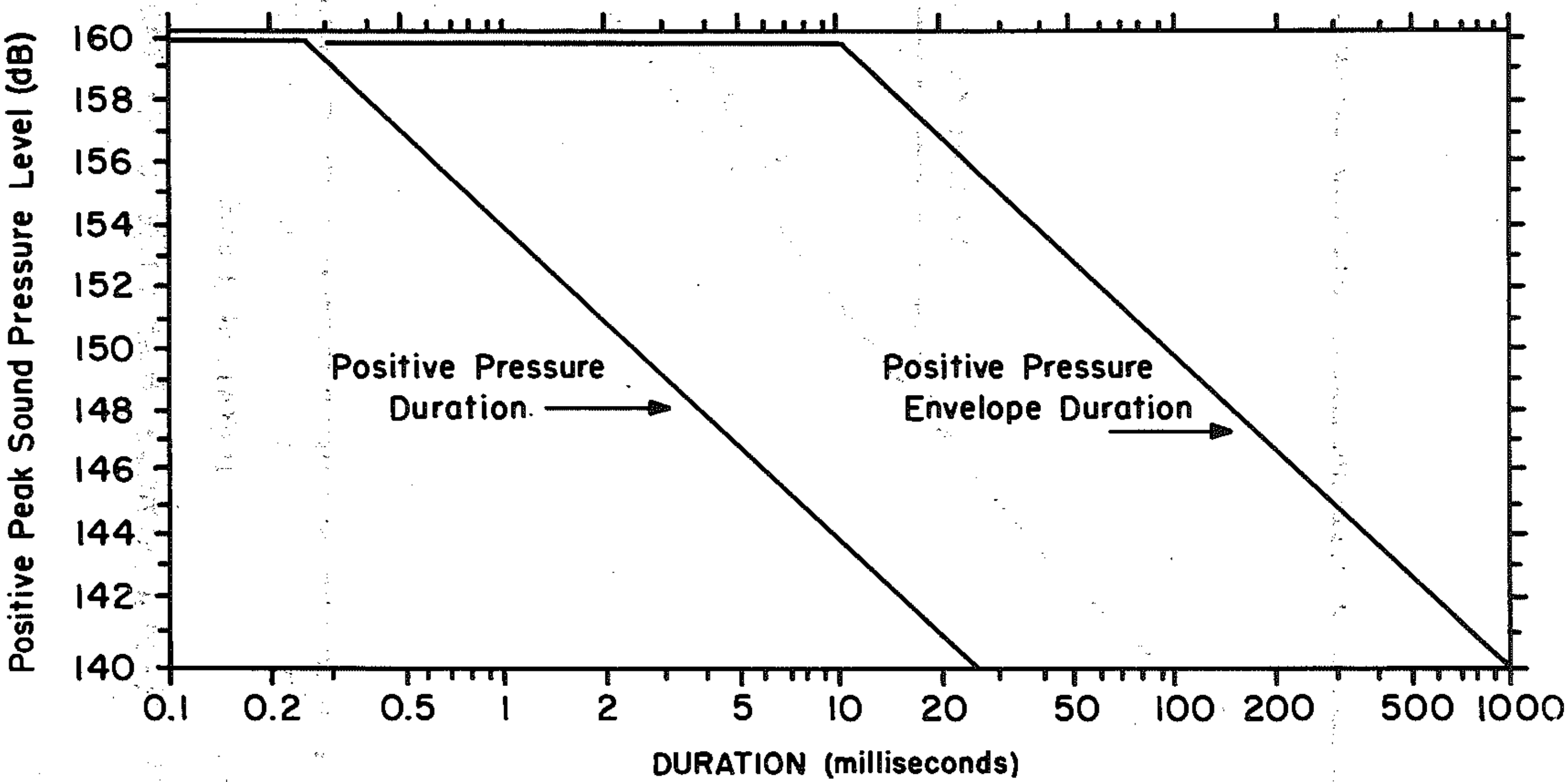


Fig. 10 Maximum Acceptable Impulse Noise Parameters for Army Materiel Command Small Arms (57)

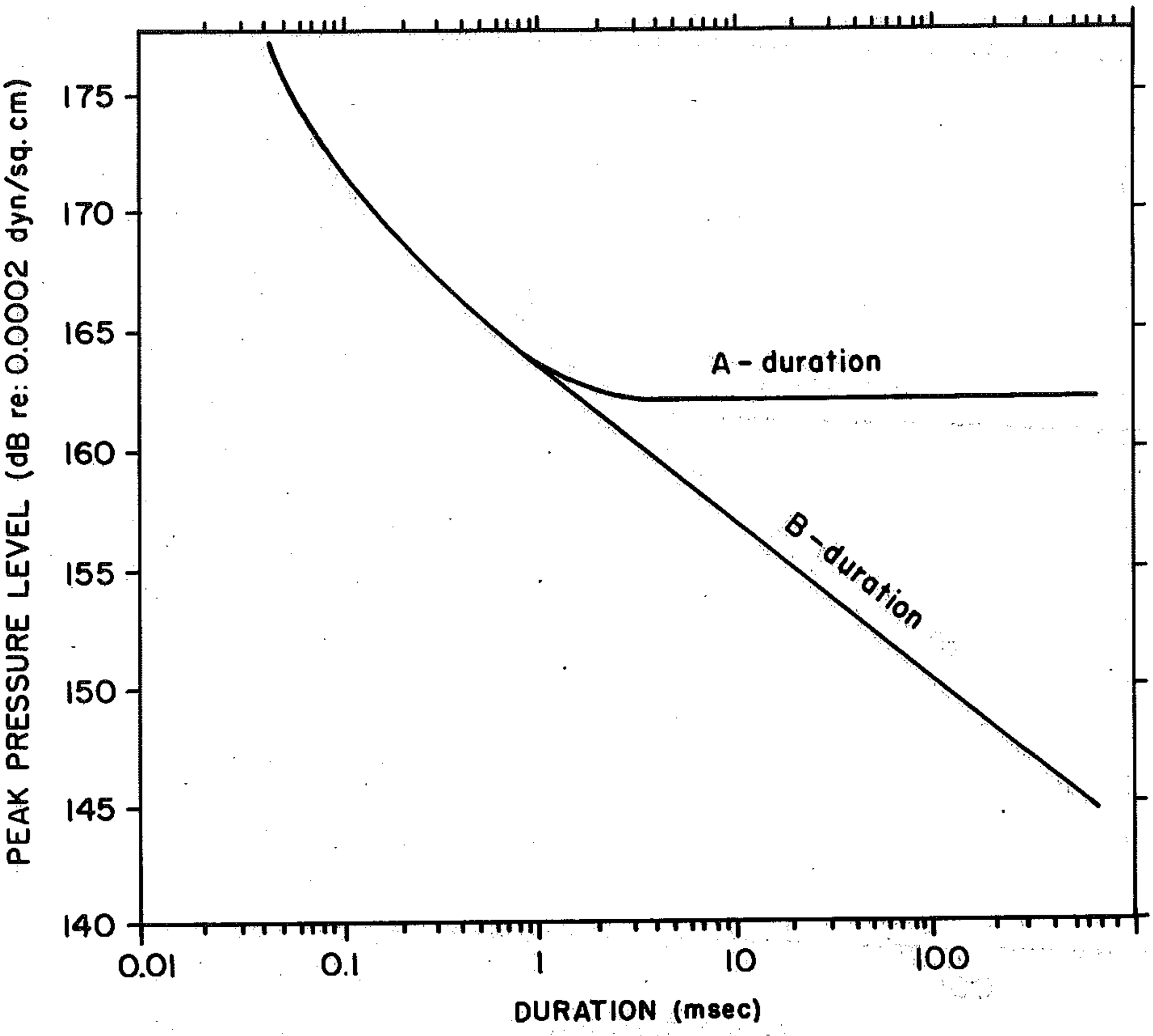


Fig. 11 Recent Damage-Risk Criteria for Impulsive Noise

It will be noted that the acceptable exposure given in Figure 10 is lower than that of Figure 11. Considering the amplitude and duration of, for example, the M-14 rifle (about 159 db at about .3 msec. duration)at the firer's ear (62), it would appear to minimally meet the HEL standard and effectively meet the DRC (except for the most susceptible persons) or for impulses of the indicated magnitude and duration normally incident on the ear.

For the 155 mm howitzer (amplitude,under certain conditions,of about 185 db at about 5 msec. duration) (63), the exposure far exceeds the DRC limits unless properly fitted, good quality ear protection is utilized. Again, additional risk could be expected for the most susceptible individuals and for impulses which are normally incident on the ear.

Problems for Further Investigation:

1. Definition of the problem in general:

Although the urgency of requirement and desire, that is in evidence for the ballistic environment, has not been evidenced for the generalized acoustic environment, nevertheless many requirments exist and are recognized.

Protection may be divided into three areas, overall vibration, overall blast, and noise effects on delicate tissue (most prominent of which is the ear). In addition to protection, perception and communication in an acoustic environment are also significant. Most military acoustic environments involve all three hazards, but most of the recent developments in generalized acoustic protection have been in the area of the aircrewmen's helmet and the blast protective boot.

2. Specific acoustic problem areas of the Military:

a. Noise and vibration in helicopters: (15) The noise level in helicopters is considered somewhat excessive. In a particular case (H-13-4 helicopter), the noise level at the pilot's ear reaches a level of approximately 110 db over a range of about 75-150 cycles per second. The noise level considered acceptable is 104 db over a range of 75-500 cycles per second.

In addition, pilots feel that they require 7 db lower noise level above 2400 cps. The acceptable noise level in this region is about 75 db but, in many instances, levels (near the pilot's ear) reach 80 to 90 db in this frequency region.

Fatigue was observed to result from general noise, but it is not certain to what extent this is influenced by either noise or vibrations separately.

b. Damage-risk criteria (impulse): The damage-risk criterion tentatively established by "Chaba" (NRC Committee on Hearing and Bioacoustics) for unprotected ears subjected to impulse sound defines a maximum peak sound-pressure level of 140 db. However, every standard Army weapon exceeds this level. It is, therefore, essential that this problem be resolved by reduction of the sound pressure level presented to the ear. This, in turn, requires more definitive damage-risk criteria (although major advances have been made)(59).

c. Blast protection to artillery crewmen: The intensity of proposed high energy artillery is sufficiently high that a problem of injury exists to physiological systems other than the ear. It has been recommended that personnel not be exposed to impulses greater than 7 psi. The anticipated intensities in the crew area for proposed artillery, however, are on the order of 30 psi.

d. Noise from jet planes: In most cases, the pilot is well protected from the exhaust noises by his cockpit, canopy, and earphones. Maintenance men, however, operate within the noise field which can attain sound pressure levels on the order of 130-140 db overall. Such sound pressure levels are far above those that cause permanent hearing loss if exposure is repeated over a period of years. In addition, the onset of pain is a poor warning of impending injury, since the pain threshold is about 140 db overall.

e. Development of improved sound attenuation in helmets: Research and development projects are in progress and should be continued.

f. Development of improved ear plugs for gun crewmen: Although the present standard ear plugs are adequate attenuators when properly utilized under conditions presented by current weapons, they probably will not be adequate for proposed higher energy weapons. In addition, present ear plugs are uncomfortable, not easily utilizable, and have a tendency to loosen and fall out under severe activity.

g. Improvement of blast protective footwear: Present blast protective footwear provides approximately 65% saves (i.e.--reduction in amputations) and 100% saves with an additional device when utilized against an M-14 type mine. Continued work in this area is desirable in order to afford protection against more powerful mines.

h. Study the limitations of available protective devices: Although the limitations of most protective devices have been evaluated against specific hazards, the studies are not comprehensive. Such studies should be continuous and follow the trend of varying hazards.

i. Study and maintain a file of all acoustic hazards from the various equipment utilized by the military: The developers of protective devices are continually in need of information relating to military hazards. Although many such hazards have been studied, there are many others which require study. Such studies would be coordinated with the Office of the Surgeon General (as indicated by the Army Concept Team in Vietnam) and a file of the various hazards maintained for use by protective device developers.

j. Basic and Applied Research in Physical, Physiological, and Psychological Acoustics: The need for research in state-of-the-are areas is quite evident from the many instances of lack of preparation for a specific requirement. There are at present several technological requirements which are stymied for want of further advances in the state-of-the-art. Other areas of technology suffer from the need to translate available state-of-the-art information into technology through applied research.

Specific areas for which advances are necessary are:

(1) Non-degradable acoustic energy absorbing materials

(2) Further definition of blast attenuation concepts

(3) Further definition of the strength of materials under transient loading with consequent wave propagation

(4) Further utilization of generalized acoustics for diagnostic purposes.

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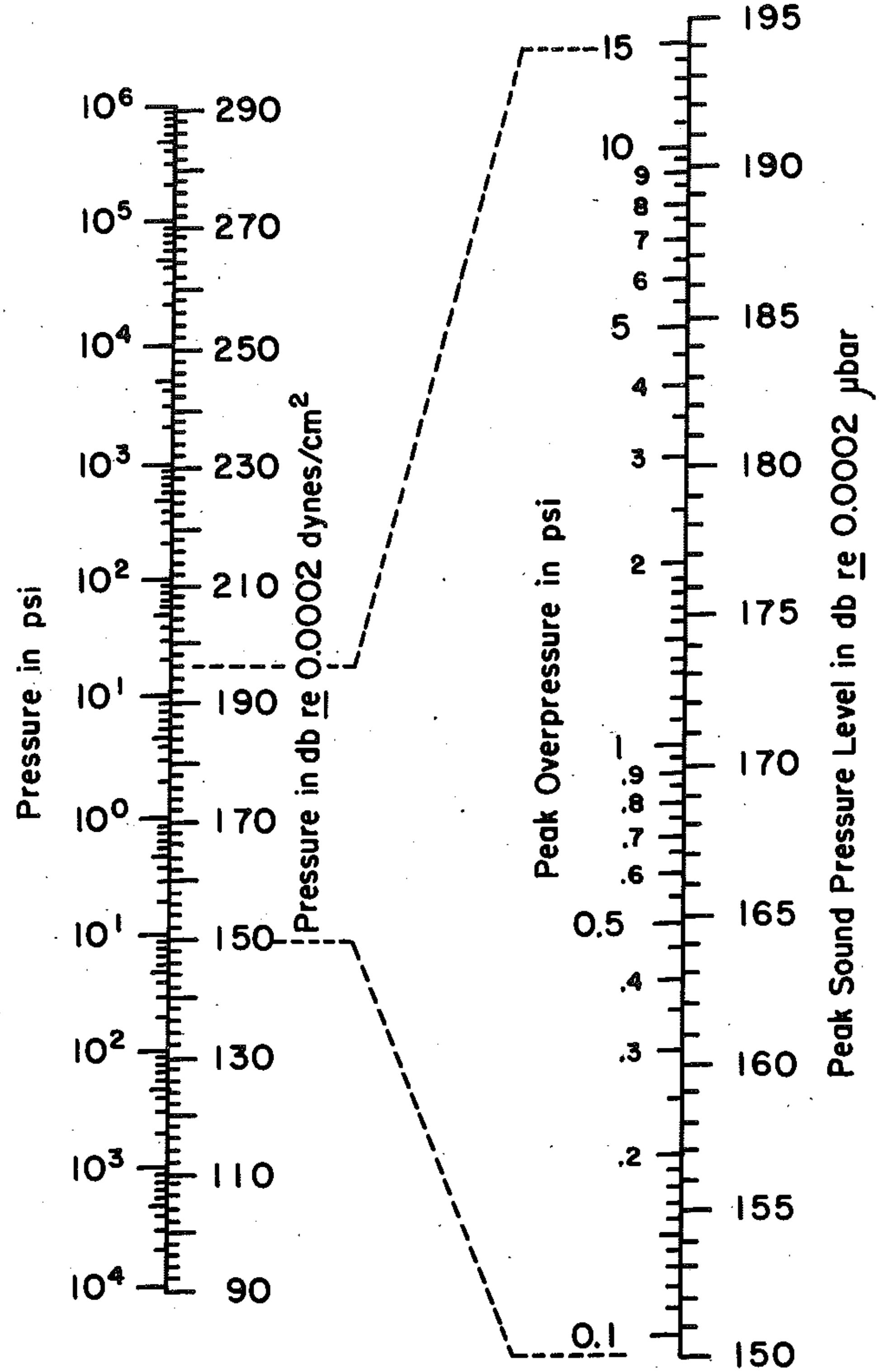
# Appendix

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13. ABSTRACT

A review has been made of the literature in the area of acoustics, vibration, shock, and blast phenomena related to effects on the physiological system and attenuation effects of materials and devices.

In addition, information from sources other than the literature pertinent to an evaluation of the significance of acoustic hazards in the military environment, is also presented.

This review has demonstrated the severe acoustic hazards presented by the military environments and the inadequacy of presently available attenuating devices.

Damage-Risk and Standards Criteria are presented, and further studies are suggested to advance the state-of-the-art in acoustic hazards protection as well as to exploit the potentials of acoustic phenomena for the investigation of material properties.

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| Shock | 9 | | 6 | | | |
| Vibration | 9 | | 6 | | | |
| Noise (sound) | 9 | | 6 | | | |
| Protection | 4 | | 8,4 | | | |
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